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ON-LINE FORMATION MEASUREMENTS AND PAPER QUALITY

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ABSTRACT

The quality of many paper and board products is highly dependent on formation, although this dependence is not always easy to quantify. This paper will briefly consider the relationship between a number of paper properties and formation. Both off-line and on-line formation measuring instruments will be reviewed, including some results of evaluations which have been performed at the Institute of Paper Science and Technology for the Measurement Technology Committee of the American Forest and Paper Association (AF&PA).

1. INTRODUCTION

Everyone seems to agree that formation is an important factor in determining paper quality. However, the relationship between formation and measures of paper quality, i.e., strength, optical properties, printability, and runnability, are quite complex and certainly other variables are involved. Perhaps the dependence of visual uniformity on formation is the only paper quality for which a one-to-one relationship exists, although even this is probably an oversimplification. Therefore, it is often quite difficult to precisely determine the contribution formation has made to a paper's performance. This author is not aware of any comprehensive studies that have been done to determine the interaction and impact of formation on paper properties. For a paper-machine study this would be a major undertaking. Ideally it would be of value to have in addition to a formation sensor, on-line sensors for basis weight, caliper, surface roughness, optical properties, moisture, ash, elastic properties, and moisture content. Factor Analysis as used recently by Howard, Poole, and Page (1) might be a useful tool in such a study.

The term formation is widely interpreted, and we do not yet have an agreed definition or standards of measurement, although a universal index of formation was recently proposed (2). Formation is concerned with the small scale (0.1 mm to 100 mm) grammage variation of paper and board, a basic structural parameter to which other small-scale variations in properties may be related, e.g., optical properties, porous properties, thermal properties, surface roughness, surface energy etc. Even if we have a satisfactory instrument to measure formation, e.g., small-scale grammage, there are many different ways in which this information can be presented and used (3),(4), and (5). The situation may be further complicated when we consider the mass distribution of other papermaking materials, i.e., fillers, sizing agents, and coatings.

Despite a lack of direct evidence for quality improvements associated with good formation, efforts are always ongoing to improve it. In general we know that as headbox consistency increases, formation deteriorates. Furthermore, increasing fiber orientation also has an adverse effect on formation; however, recent developments in twin and top wire formers have not only improved sheet formation, but also reduced its dependence on fiber orientation as recently presented by Malashenko (6).

Formation measuring methods include optical e.g., laser, video, C^{14} beta radiography, beta sources P^{147}, x-ray, and electron beam techniques (3),(7), and (8).

Nearly all commercial off-line and on-line formation measuring instruments employ transmitted light, and in some cases reflected light, and use a variety of scanning modes. Exceptions include laboratory research instruments and the Ambertec device (9) which uses a promethium 147 source. Recent commercial instruments for the off-line and on-line measurement of formation are summarized in Tables 1 and 2. Each instrument has its advantages and disadvantages and the reader is referred to the Measurement Technology Program Reports (10), (11) of AF&PA (formerly API) for a more in-depth evaluation of some of the instruments given in Tables 1 and 2. It should be emphasized that of the instruments evaluated, i.e., those marked with an asterisk, some have been discontinued while others have been modified and improved.

Formation is also an important consideration in board performance; especially linerboard, which is expected to meet the ever increasing demands of customers for high levels of flexographic printability (12). However, as recently noted by Zang and Aspler (13), the factor of formation has yet to be investigated. A higher basis weight and opacity can limit our ability to measure the formation of unbleached linerboard. Furthermore, linerboard is generally not a single-ply structure. Therefore the relative importance of formation of the top and bottom plies as well as its measurement, has yet to be determined.

In the studies (10),(11) referred to above, off-line and on-line instruments were evaluated with respect to their ability to measure the visual uniformity of paper. Some of the methodology used and results obtained from these instrument studies are given in later sections of this report.

2. EXPERIMENTAL METHODS

A formation tester developed at IPST (14) was used as the basis of comparison for the instruments evaluated. The IPST Formation Tester has the capability of making both optical and small-scale grammage (mass density) measurements using a fixed aperture size of 1 mm x 1 mm. The sample size can be varied from that of a postage stamp to small rolls of paper. In the case of the latter, a special attachment is used as shown in Figure 1. The area over which formation measurements are usually made is 80 mm x 80 mm.

As noted in the last section, visual uniformity is one paper-related quality variable which is most directly related to formation. In this investigation visual uniformity was determined using a pair comparison technique (15) which provides a quantative assessment of visual uniformity. For n samples, the number of pairs is given by n(n-1)/2. the maximum score 2(n-1), and the average score (n-1). The number of illogical triads was also determined. The same pair comparison technique was used for both the off-line and on-line formation measuring instrument evaluation. The procedure allows the judge to decide what is uniform, and generally there is a concensus between experienced and inexperienced judges.

Off-Line Formation Measuring Instruments

For the evaluation of off-line formation measuring instruments, paper types included newsprint, tissue, offset, bond, and medium. Paper samples for formation measurements and visual uniformity assessment were obtained from production. Formette Dynamique and Noble and Wood Former handsheets were made from reslushed couch samples obtained for the above grades.

The papermaking variables we evaluated included furnish, five levels of formation level, color, average grammage, and three levels of fiber orientation.

On-Line Formation Measuring Instruments

On-line formation sensors usually require a moving web from which formation measurements can be obtained. Various options were considered for evaluating on-line formation sensors; however, the availability of IPST's web transport system, which had been fabricated under a U.S. Department of Energy (DOE) contract for the development and evaluation of on-line ultrasonic sensors, appeared to satisfy our needs.

The web transport system has a speed range of 0 to 2500 fpm, and can operate in either a reel- to-reel mode, or continuously using an endless belt as shown diagramatically in Figure 2.

The ability of the instrument to measure the visual uniformity of selected grades of paper was the main feature to be evaluated. Other factors investigated which might affect this measurement include grammage, color, fiber orientation, web speed, web flutter, ambient lighting, and sampling window. The paper grades were identical to those used in the off-line instrument evaluation, except that medium was replaced with sack kraft.

Rolls of paper (9-in to 14-in wide) for each grade were supplied by members of the Measurement Technology Committee of American Forest and Paper Association (AF&PA). Belt samples 35 feet in length were prepared together with 8.5-in x 11.0-in samples taken before and after each belt. The measurements made on the 8.5-in x 11.0-in samples are given in Table 3.

Characterization of Belt Formation Samples

Using the IPST Formation Tester, as shown in Figure 1, formation measurements (using transmitted light) are made along the center line and at ±1 cm from the center line. The length of the scan was approximately 21 ft, i.e., 6400 data points. In the absence of any large scale nonuniformities, it was believed that a formation measurement, i.e., the coefficient of variation of transmitted light, based on line scan should agree with that taken over an area of the web.

Sensors

The principle of operation of the four on-line sensors evaluated is shown in Figures 3, 4, 5, and 6 for the F-Sensor, Spectraform, Optipak, and Lippke sensors, respectively. The F-Sensor uses He-Ne laser; the Spectraform a tungsten halogen lamp; the Optipak, a white light source; and the Lippke; a laser diode.

3. RESULTS AND DISCUSSION

Off-Line Formation Measuring Instruments

A reasonable correlation between formation index and visual ranking was found for all of the instruments evaluated (10).

Figures 7 and 8 illustrate this correlation for newsprint for the IPST and Robotest instruments, respectively. We note that the formation index was different for each instrument. The inverse of the coefficient of variation of transmitted light was used for the IPST Formation Tester, i.e., 1/CV(T) calculated for 6400 data points. The Robotest, which employs image analysis techniques, has a formation index ranging from 20 to 122.4. The higher the formation index, the better the formation.

Interestingly when only handsheets were used to establish the correlation between formation index and visual ranking, the correlation was much weaker or non-existent as illustrated in Figures 9 and 10 for newsprint for the Robotest and IPST instruments, respectively. Therefore even though the eye can detect differences in visual uniformity, albeit small differences for handsheets, none of the instruments was sufficiently sensitive to detect these differences, particularly for the newsprint.

On-Line Formation Measuring Instruments

A comparison of formation measurements made on the belt samples and on the 8.5-in x 11.0-in samples is shown in Table 4 for the tissue, offset, newsprint, and sack kraft samples. On the whole, there is very good agreement between the methods of measurement. These results essentially confirm Jordan's (16) contention that the line scan method is not flawed, provided we are not seeking textural or pattern recognition information.

As with the off-line formation measuring instruments, all of the on-line instruments provided a reasonable correlation between their particular formation index and visual uniformity as shown in Figures 11 through 14.

A schematic diagram of the SpectraForm is shown in Figure 4. "Floc Intensity" is the basic index of formation and is supposedly a measure of the coefficient of variation of mass density or grammage. It is obtained by taking the RMS value of the AC signal, which has been converted to a DC signal, and multiplying it by a grade dependent slope, i.e., a = d(ln DC)/ d(BW). This signal is then divided by the average, or nominal, basis weight to obtain the coefficient of variation of mass density CV(W). The larger the "Floc Intensity," the poorer the sheet formation.

The variation of the "Floc Intensity" with Visual Ranking for the offset samples is shown in Figure 15. Also, shown in Figure 16 is the variation of "Floc Intensity" with the IPST Formation Tester Index CV(T). In general the correlation shown in Figure 16 is quite good; however, we note that the correlation between SpectraForm and IPST Formation Tester indexes is not independent of color (green), since no color correction has been made for the IPST tester.

4. CONCLUSIONS

The influence of formation on paper properties, particularly with respect to their on-machine measurement, has been briefly considered. A brief review has also been given of programs supported and funded by the Measurement Technology Committee of the American Forest and Paper Association. The performance of both the off-line and on-line formation measuring instruments has been mainly limited to their ability to measure visual uniformity, i.e., establishing a correlation between visual ranking and the instrument's formation index.

The on-line formation measuring instruments were evaluated using a web transport system which had been funded by the Department of Energy for an on-line ultrasonic sensor development project. It was found for the tissue, newsprint, offset, and sack kraft grades evaluated that line-scan measurements were in close agreement with area-scan measurements.

It was also found that both the off-line and on-line instruments are able to measure visual uniformity, providing there are reasonably large differences in visual uniformity.

5. LITERATURE CITED

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Table 1. Commercial Off-Line Formation Testers

1. MKS Microformation Tester
2. MKS 3-D Sheet Analyzer
3. RoboTest PaperLab 1
4. PAPRICAN Microscanner
5. Reed NUI
6. Optomax Inc. Image Analysis System
7. Ambertec Beta Formation Tester
8. Toyo Seki

Table 2. Commercial On-Line Formation Testers

1. Measurex - 2275 MassForm and 2276 SpectraForm
2. ABB (Accuray) Optipak
3. Valmet Formatel
4. Thermoelectron - F Sensor
5. MKS On-Line and Portable On-Line
6. Systronics Inc. - Formspec (Albany International)

Table 3. Measurements Made on 8.5-in x 11.0-in Formation Samples

* Grammage
* Caliper: TAPPI and IPST Soft Platen
* MKS Formation Index
* IPST Formation Tester
* Emd/Ecd
* Pair Comparison Tests
* Optical Properties

Table 4. Comparison of Formation Measurements on Belt and 8.5-in x 11.0-in Samples

TISSUE		OFFSET		NEWSPRINT		SACK KRAFT	
80x80 (CV) %	LINE (CV) %	80x80 (CV) %	LINE (CV) %	80x80 (CV) %	LINE (CV) %	80x80 (CV) %	LINE (CV) %
30.6	26.1	14.9	15.5	12.8	12.6	26.4	26.7
22.4	21.3	7.7	8.0	9.2	10.1	25.4	26.5
19.4	20.5	5.4	5.7	9.8	9.8	24.8	26.1
20.6	22.2	7.2	7.1	8.4	8.8	40.2	38.2
25.4	26.6	6.0	6.3				
30.3	31.4	4.0	4.1				

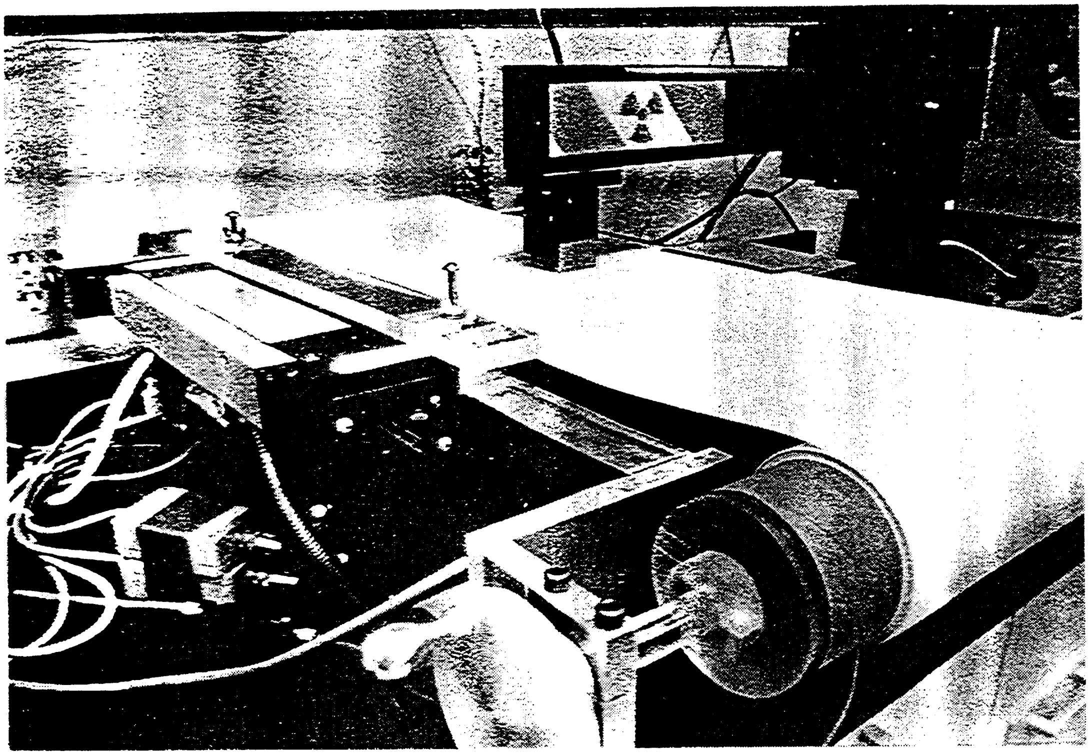

Figure 1 IPST Formation Tester with Belt Sample Attachment

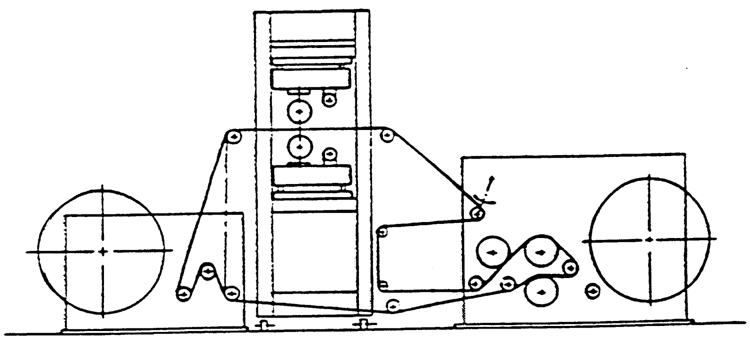

Figure 2 Diagram of Web Transport System

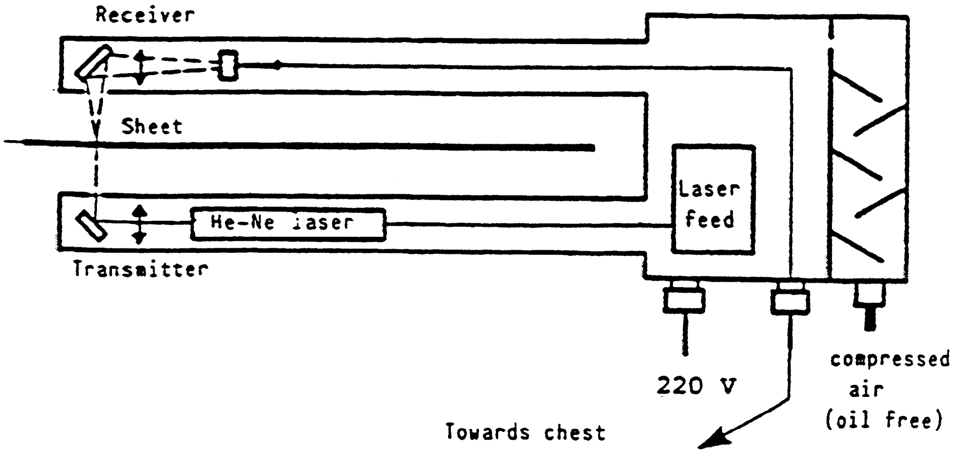

Figure 3 Diagram of F-Sensor

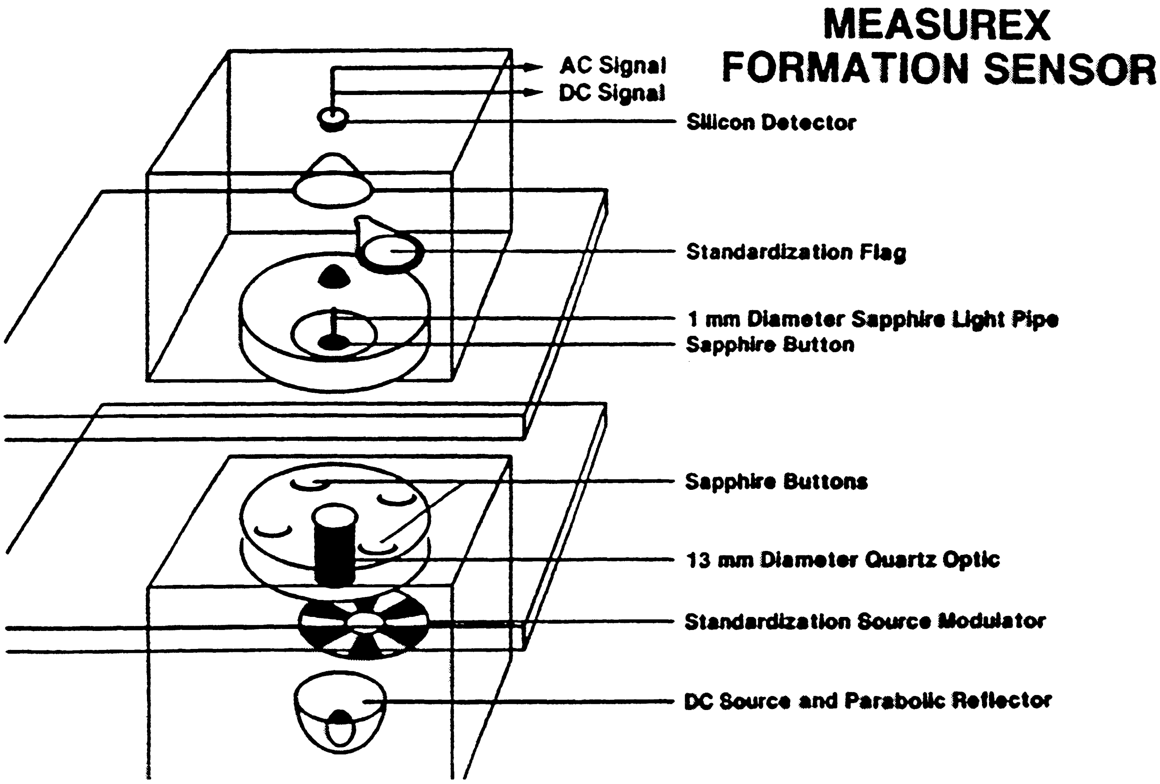

Figure 4 Diagram of Spectraform Sensor

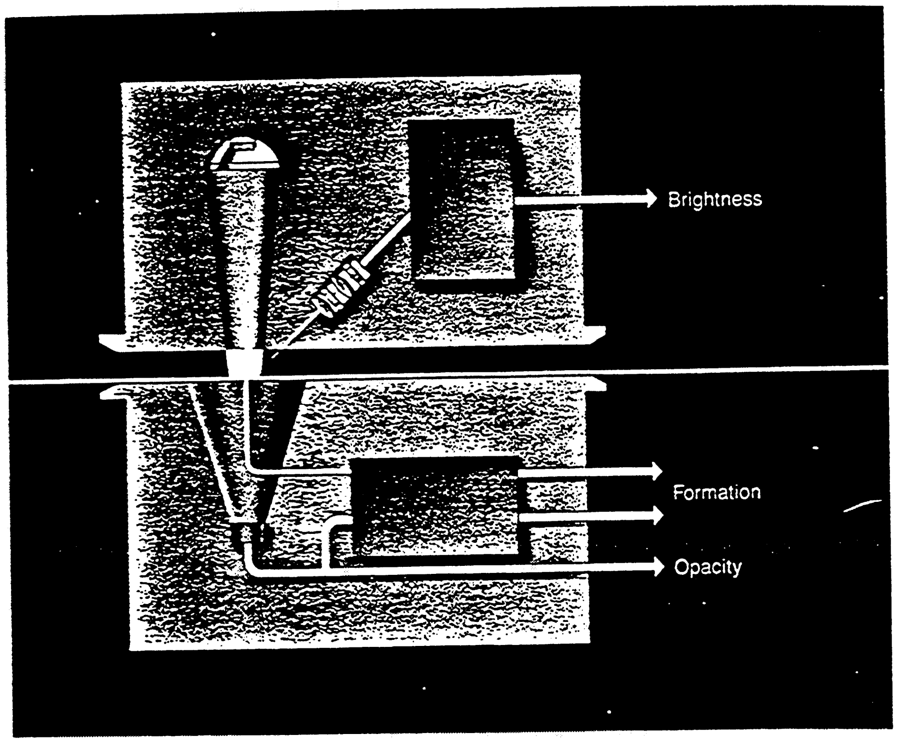

Figure 5 Diagram of Optipak Sensor

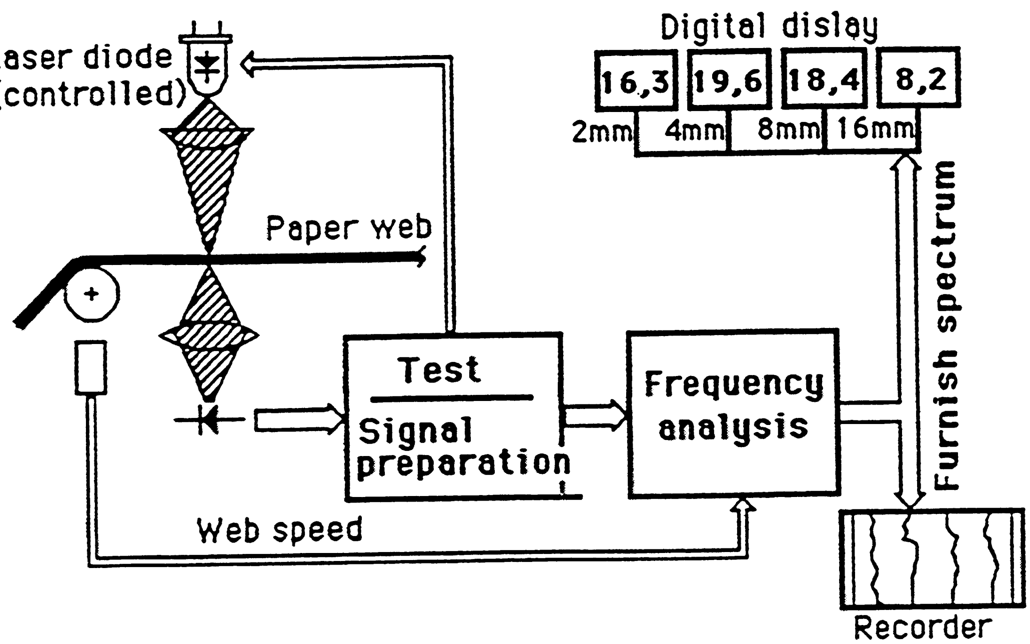

Figure 6 Diagram of Lippke Sensor

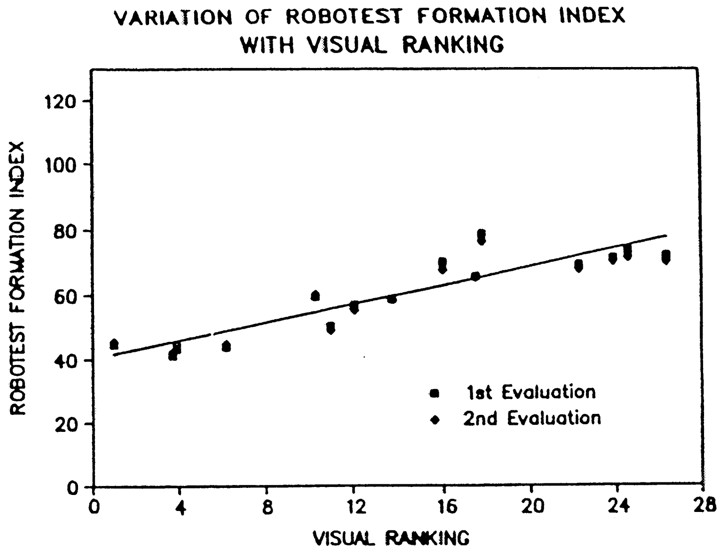

Figure 7 Variation of Robotest Formation Index with Visual Ranking for Production and Handsheet Samples of Newsprint

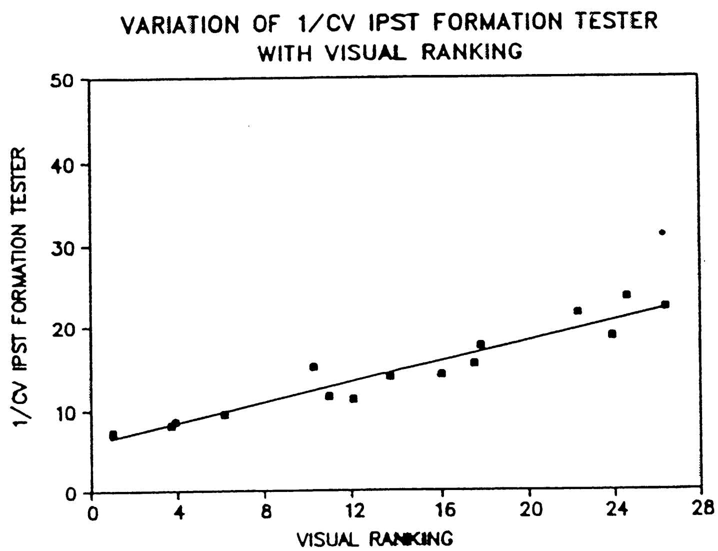

Figure 8 Variation of 1/CV(T) IPST Formation Tester with Visual Ranking for Production and Handsheet Samples of Newsprint

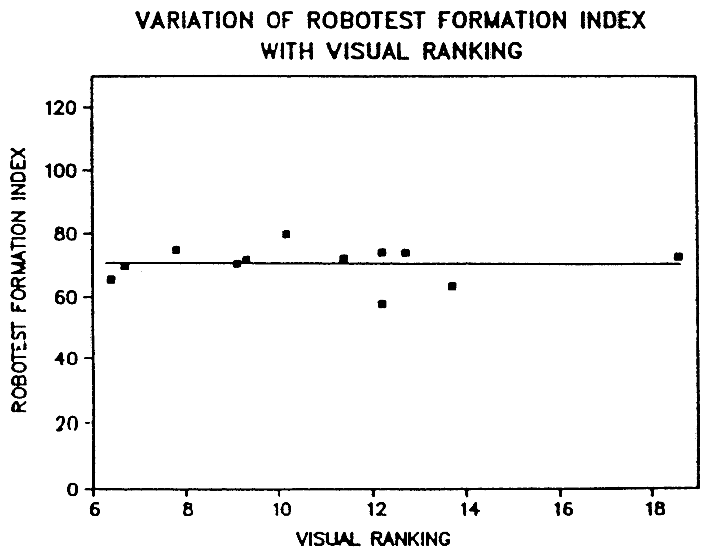

Figure 9 Variation of Robotest Formation Index with Visual Ranking for Only Formette Handsheet Samples of Newsprint

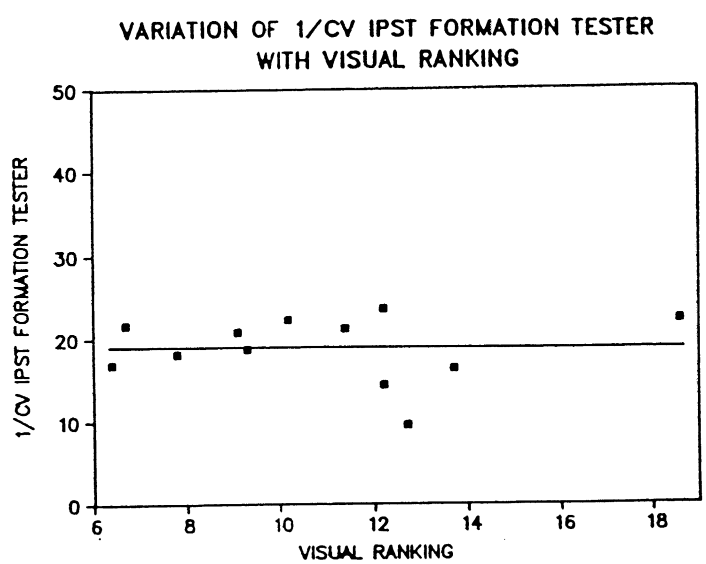

Figure 10 Variation of 1/CV(T) IPST Formation Tester with Visual Ranking for Only Formette Handsheet Samples of Newsprint

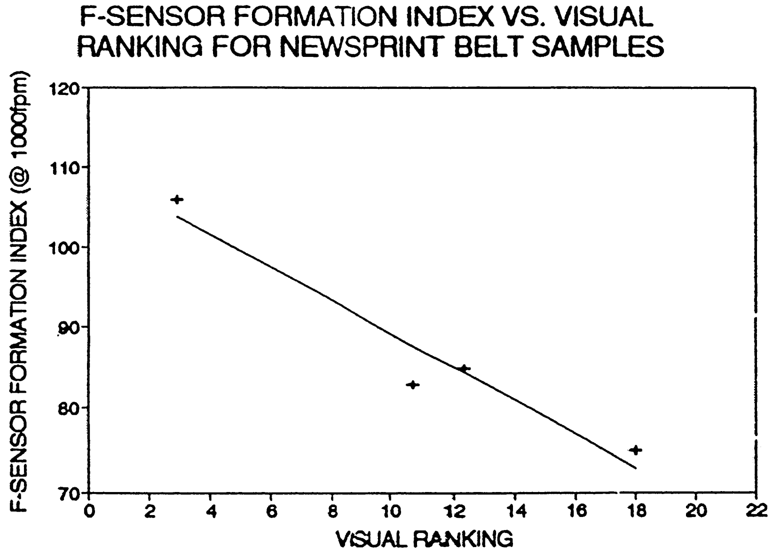

Figure 11 F-Sensor Formation Index Versus Visual Ranking for Newsprint

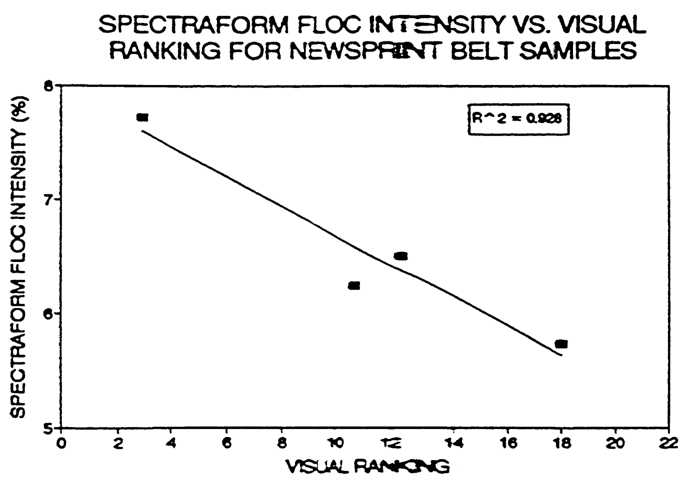

Figure 12 Measurex Spectraform Floc Intensity Index Versus Visual Ranking for Newsprint

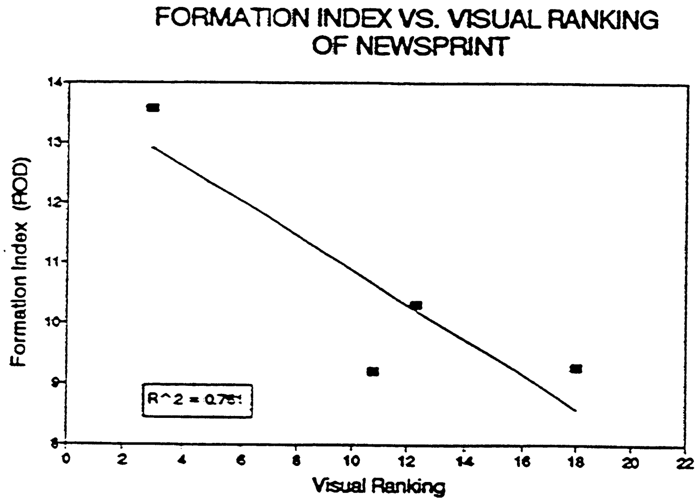

Figure 13 ABB Optipak Formation Index (ROD) Versus Visual Ranking for Newsprint

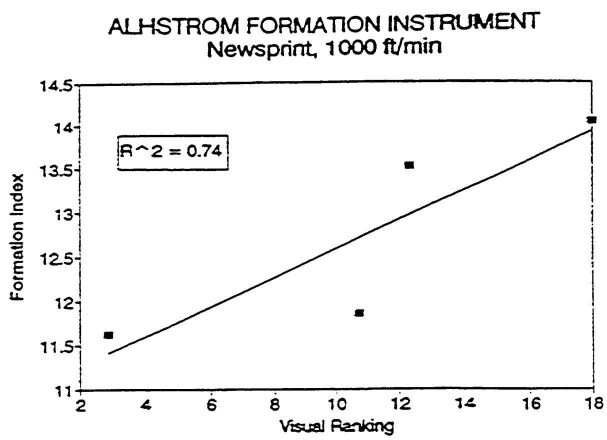

Figure 14 Ahlstrom Formation Index Versus Visual Ranking for Newsprint

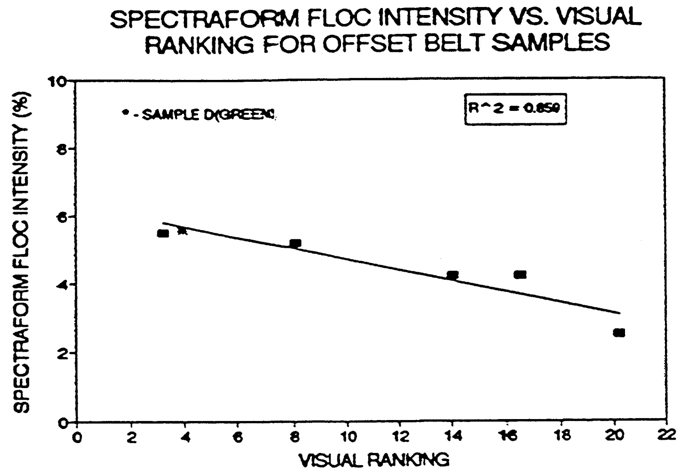

Figure 15 Measurex Spectraform Floc Intensity Index Versus Visual Ranking for Offset

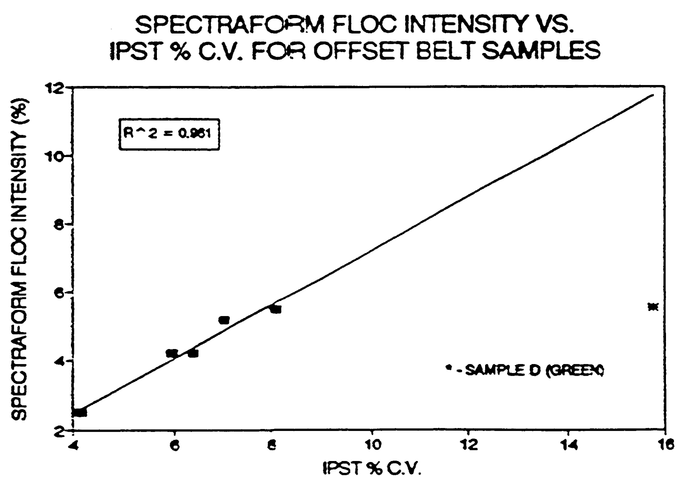

Figure 16 Measurex Spectraform Floc Intensity Index Versus IPST Formation Index for Offset